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STUDIES OF LUNG VOLUMES IN INSTRUCTORS AT THE ESCAPE TRAINING TANK

by

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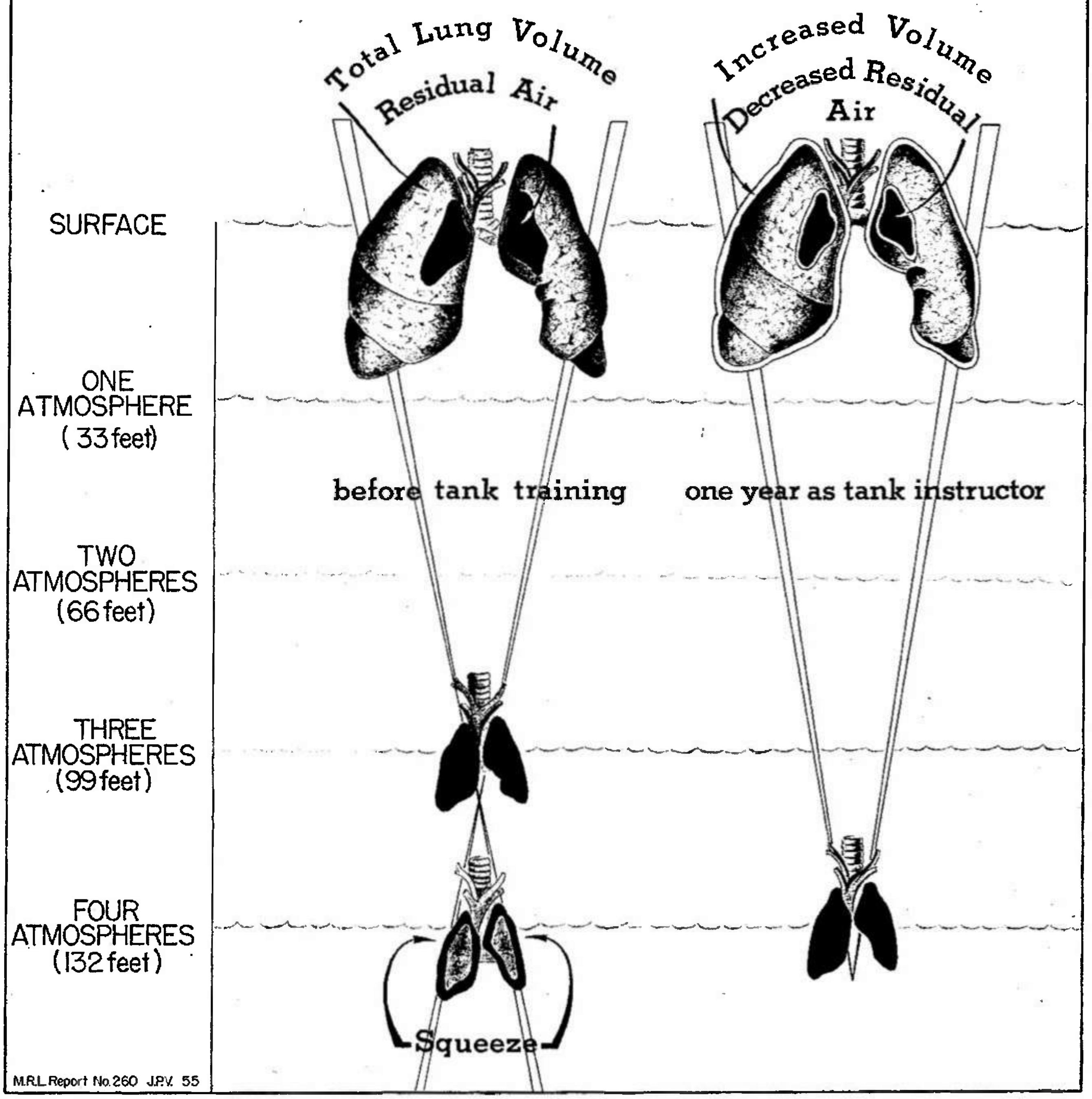
Bureau of Medicine and Surgery, Navy Department
Project NM 002 015.12.01

EFFECT OF SKIN DIVING ON LUNG VOLUMES

INCREASED TOTAL CAPACITY OF THE LUNGS PLUS A SLIGHT DECREASE IN RESIDUAL AIR ALLOWS DIVER TO REACH GREATER DEPTH WITHOUT A SQUEEZE



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Released by

Gerald J. Duffner
Commander, MC, U.S. Navy
Officer-in-Charge
26 November 1954

THIS REPORT CONCERNS.....

studies of lung volumes of instructors at the Escape Training Tank, over a period of one year.

IT IS FOR THE USE OF.....

submarine medical officers, physiologists, and others concerned with problems of underwater swimming.

THE APPLICATION FOR SUBMARINE MEDICINE:

It has been found that vital capacity, inspiratory reserve, tidal volume, and total capacity of the instructors increase during one year of duty at the Escape Training Tank, indicating an adaptation to skin diving. These findings have a bearing on selection of effective underwater swimmers and problems of health protection in underwater swimming.

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ABSTRACT

Based on a common experience of instructors at the Escape Training Tank, namely, that during their tour of duty, they learn to hold their breath longer and breathe differently, a study of their pulmonary capacities was undertaken. Vital capacity, inspiratory reserve, and total lung capacity of the Tank instructors were found significantly larger than those of a group of laboratory personnel representing average individuals. When measured vital capacities of the two groups were compared with vital capacities predicted on the basis of body surface area, the measured values of the Tank instructors were 14.6 per cent higher than predicted, while those of the laboratory personnel were 0.56 per cent lower. A longitudinal study of the lung volumes of instructors performed over a period of one year following their assignment to the Escape Training Tank demonstrated a significant increase in inspiratory reserve, tidal volume, vital capacity, and total lung capacity, while expiratory reserve and residual volume did not change significantly. These findings indicate an adaptation of the lung volumes to the stress of skin diving.

STUDIES OF LUNG VOLUMES IN INSTRUCTORS AT THE ESCAPE TRAINING TANK

INTRODUCTION

Observations in the laboratory as well as in practice suggested that in the course of their duties the instructors at the Escape Training Tank underwent some changes in their pulmonary capacity. For example, it was found that the instructors could hold their breath much longer than the average individual.

The instructors at the Escape Training Tank are engaged almost daily in "skin diving", that is diving without the use of any special equipment. The instructors take a breath of air at the surface, descend in the Tank to depths as great as 100 feet, and return to the surface while holding their breath. They also make "free ascents", which means that while in an air lock at 25, 50, or 100 feet under water they take a deep breath, step out of the lock into the water and float to the surface, exhaling the expanding air in their lungs as they rise. The free ascent is performed by the instructors as they guide the Submarine School students through a series of escapes from the air locks. The student uses the Submarine Escape Appliance, a self-contained breathing apparatus, during his ascent to the surface. If the student has become thoroughly familiar with this ascent technique, he is given the opportunity to perform free ascents himself.

Skin diving involves the potential hazard of a squeeze. During free escape the danger exists of overdistention of the lungs, with possible rupture (1, 2). Kinsey (3) published a report on four cases of air embolism as a result of submarine escape training. Even in proper execution of skin diving and free ascent there is a certain amount of stress imposed on the lungs; this is readily demonstrated by considering the pressure-volume relationships in the lungs.

The pressure at 100 feet is equal to four atmospheres absolute. Therefore, a volume of air inhaled at the surface will be compressed to one quarter of its original volume at that depth; conversely, a lungful of air inhaled in the air lock at 100 feet will expand to four times its volume when reaching the surface. (While stationed in the 100-foot lock, during escape training, the instructors may be exposed to four atmospheres absolute pressure for periods up to 20 minutes.)

We were interested in knowing whether the instructors do adapt to the stress of skin diving by increasing their lung volumes. This would explain their observations that, during their tour of duty, they learn to hold their breath longer and breathe differently.

MATERIAL AND METHODS

Three groups of subjects were studied. Group A consisted of 16 instructors at the Escape Training Tank who had carried out "in-the-water" instruction for an average period of one and one-half years. Group B was composed of 16 adult male personnel from the Medical Research Laboratory. After it was found that the lung volumes of the Tank instructors were markedly larger than those of the laboratory personnel, a longitudinal study was performed on a group of 20 Tank instructors. Pulmonary capacities were measured within the first two months of their tours of duty at the Escape Training Tank and after approximately one year. In a group of eight subjects, additional determinations of the lung volumes were made with the subjects standing on a ladder up to the neck in water. Under these conditions the intrapulmonic pressure in reference to the ambient water pressure was measured at -20 mm. Hg.

Total lung capacity and its subdivisions were studied and the measurements taken as follows:

1. Vital capacity, as measured from the maximum expiration following a maximum inspiration, was determined using the Collins Vitalometer, the highest value of three successive trials recorded.

2. Inspiratory and expiratory reserve and tidal volume were measured using the Collins Respirometer. The soda-lime canister was removed to minimize the resistance to breathing. The respirometer was flushed with room air after each measurement to prevent carbon dioxide from accumulating in the closed system.

3. Residual volume was determined by the Rahn, Fenn, and Otis modification of the Lundsgaard-Van Slyke method (4). The alveolar air samples were analyzed for carbon dioxide and oxygen content in a Scholander respiratory gas analyzer (5). All values reported were calculated to body temperature, ambient pressure and saturated with water vapor (B. T. P. S.). The determinations were carried out with the subjects in a standing position in order to make a comparison of the various pulmonary subdivisions out of the water and in the water.

RESULTS

Vital capacities of laboratory personnel and Tank instructors:

Vital capacities of the two groups measured with the Vitalometer were found significantly different (Table 1). The Tank instructors showed greater vital capacity. A comparison of predicted and measured vital capacities is given in Table 1. Predicted values were obtained by using the West formula, which is based on body surface area (6).

Table 1. - Comparison of Vital Capacities of Laboratory Personnel and Tank Instructors

	Predicted vital capacity based on body surface area	Measured vital capacity	Deviation of measured from predicted vital capacity (Predicted vital capacity based on body surface-100%)
	Liters (B.T.P.S.)	Liters (B.T.P.S.)	Percentage
		LABORATORY PERSONNEL	
1	5.25	3.89	- 26.0
2	4.40	4.02	- 8.6
3	5.02	5.00	- 0.4
4	4.87	3.80	- 22.0
5	4.60	4.47	- 3.0
6	4.70	5.82	+ 23.9
7	4.92	5.47	+ 11.0
8	5.02	4.52	- 10.0
9	4.63	4.67	+ 5.5
10	5.12	4.47	- 12.7
11	4.65	4.63	- 0.4
12	4.50	5.11	+ 13.5
13	5.06	4.88	- 3.6
14	5.05	5.69	+ 12.7
15	4.55	4.63	+ 1.8
16	5.50	6.02	+ 9.4
Mean	4.86	4.82	- 0.56
S.D.	.38	.62	12.91
		TANK INSTRUCTORS	
1	4.78	4.43	- 7.3
2	4.38	5.00	+ 14.1
3	4.68	5.33	+ 14.1
4	4.80	6.33	+ 31.9
5	5.10	6.25	+ 22.5
6	4.88	5.59	+ 14.5
7	4.83	5.56	+ 15.1
8	5.10	5.38	+ 5.5
9	4.65	4.90	+ 5.4
10	5.10	5.89	+ 15.0
11	4.70	5.60	+ 9.0
12	5.00	6.60	+ 32.0
13	5.00	6.27	+ 25.0
14	5.38	6.00	+ 12.0
15	4.75	5.24	+ 10.3
16	5.70	6.49	+ 13.8
Mean	4.93	5.68*	+ 14.56*
S.D.	.25	.59	9.60
P	>.1	<.001	<.001

* Difference statistically significant to the 1% level or less

The mean age for each of the two groups was not found to be significantly different, the laboratory personnel averaging 30.4 years and the instructors 30.3 years. The results indicate that the vital capacities of the laboratory personnel fall in the range of predicted values, while the vital capacities of the instructors are larger. For the group of instructors the mean measured vital capacity is significantly higher (5.68 liters) than the mean predicted value (4.93 liters) based on body surface area. The mean measured vital capacity of the laboratory personnel (4.86 liters) is not significantly different from the value predicted (4.82 liters). These values represented as percentage deviation of the measured, from the predicted vital capacities, showed the instructors to be + 14.56 per cent higher than predicted, while the laboratory personnel were - 0.56 per cent but not significantly lower.

Lung volumes of the Tank instructors and laboratory personnel (Table 2, Figure 1):

Measurement of lung volumes of the two groups revealed that the Tank instructors had significantly larger total lung capacities (6.990 liters) than the laboratory personnel (6.120 liters). Of the subdivisions of the total lung capacity, Figure 1 shows that only vital capacity, tidal volume, and inspiratory reserve are larger in Tank instructors compared with the laboratory personnel.

Table 2. - Pulmonary Capacities of Laboratory Personnel and Tank Instructors

	Laboratory Personnel c.c. (B.T.P.S.)		Tank Instructors c.c. (B.T.P.S.)
TIDAL VOLUME			
Mean	759.7		1018
S.D.	247.4		501.4
Number	16		16
P		> .1	
INSPIRATORY RESERVE			
Mean	2489*		3057.2
S.D.	491.7		698.1
Number	16		16
P		< .02	
EXPIRATORY RESERVE			
Mean	1405.4		1316.9
S.D.	523.8		482.3
Number	16		16
P		> .1	
VITAL CAPACITY			
Mean	4654.7*		5397.4
S.D.	656.1		555.7
Number	16		16
P		< .01	
RESIDUAL VOLUME			
Mean	1465.8		1592.7
S.D.	322.6		301.4
Number	16		16
P		> .1	
FUNCTIONAL RESIDUAL CAPACITY			
Mean	2871.4		3073.4
S.D.	585.8		764.8
Number	16		16
P		> .1	
TOTAL LUNG CAPACITY			
Mean	6120.2*		6990.1
S.D.	729.3		698.1
Number	16		16
P		< .01	

* Difference statistically significant to the 2% level or less.

Longitudinal study:

Figure 2 and Table 3 show the results of measurements of the pulmonary volume at the beginning of duty and after approximately one year of work in the water. It can be seen in Figure 2 that the volumes of all subdivisions of the lungs increase except that of the residual volume, which decreases.

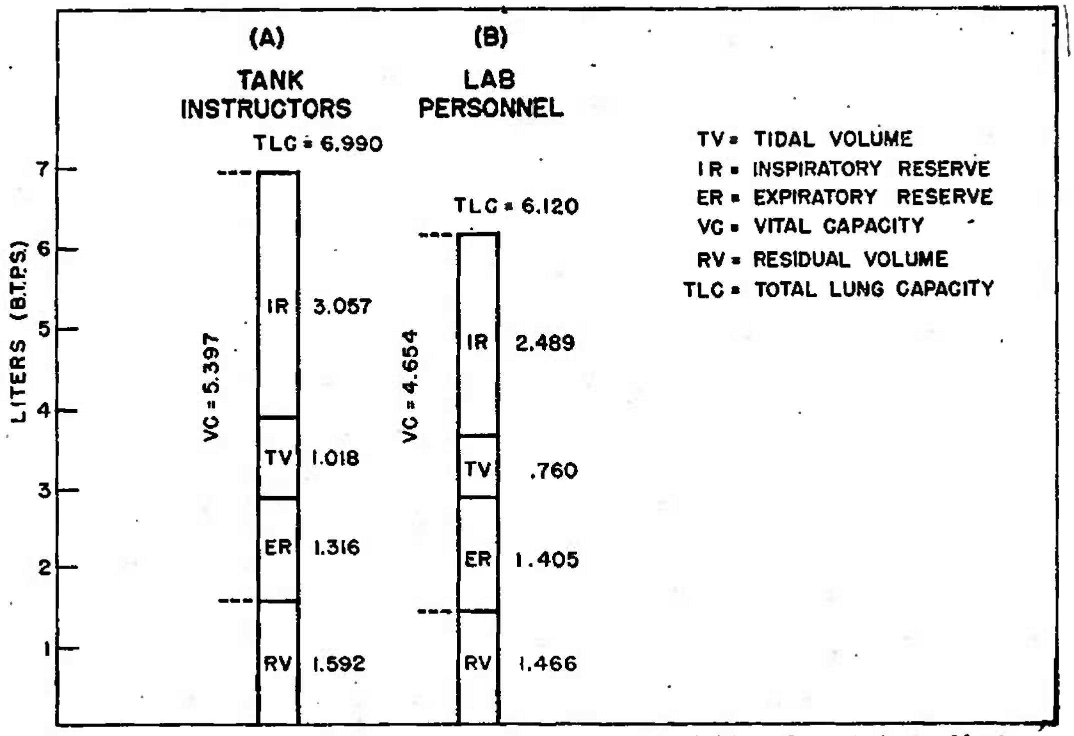

Figure I.— Mean Values Of Pulmonary Capacity And Its Subdivisions From A Group Of 16 Laboratory Personnel And A Group Of 16 Tank Instructors

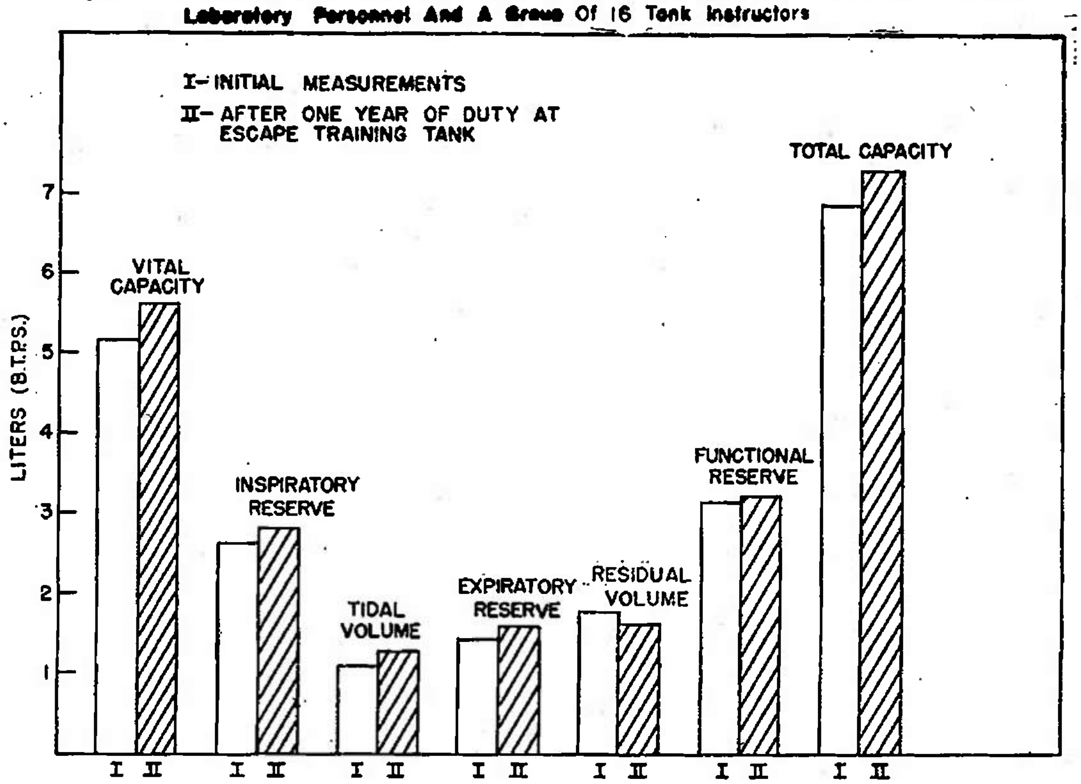

Figure 2. — Effect Of Skin Diving On Lung Volume

Table 3. - Effect of Skin Diving on Lung Volumes

	I Initial measurement c.c.(B.T.P.S.)		II After one year duty at Escape Training Tank c.c.(B.T.P.S.)
TIDAL VOLUME			
Mean	1101		1255*
S.D.	435		481
Number	20		20
P		< .05	
INSPIRATORY RESERVE			
Mean	2652		2803*
S.D.	374		432
Number	20		20
P		< .05	
EXPIRATORY RESERVE			
Mean	1424		1569
S.D.	490		530
Number	20		20
P		> .1	
VITAL CAPACITY			
Mean	5175		5629*
S.D.	622		760
Number	20		20
P		< .001	
RESIDUAL CAPACITY			
Mean	1768		1655
S.D.	499		372
Number	20		20
P		> .1	
FUNCTIONAL RESIDUAL CAPACITY			
Mean	3192		3224
S.D.	866		700
Number	20		20
P		> .1	
TOTAL CAPACITY			
Mean	6893		7274*
S.D.	971		880
Number	20		20
P		< .001	

* Difference statistically significant at the 5% level or less.

The statistical evaluation of these data given in Table 3 reveals changes that are significant in:

a. Tidal volume, which increases during the one-year period from 1.10 liters to 1.25 liters;

b. Inspiratory reserve, which increases from 2.65 liters to 2.80 liters; and, as a resultant of the above two changes;

c. Vital capacity increased from 5.17 liters to 5.63 liters;

d. Total lung capacity increased from 6.89 liters to 7.27 liters, a change significant to the 0.1 per cent level of confidence.

Expiratory reserve, residual volume, and consequently, functional residual capacity are not found to have changed appreciably.

Figure 3 and Table 4 show the results of measurements of lung volumes made on a small group of eight subjects in the water over a period of one year. It can be seen that the same lung volumes which were found to have increased after a period of one year in determinations made out of the water also increased when measured in the water, i.e. under a negative intra-pulmonic pressure of -20 mm.Hg. Because of the small number of subjects, differences do not become statistically significant, but reflect the same changes observed in examinations carried out in a larger group of subjects out of the water.

Table 4. - Comparison of Measurement of Pulmonary Capacity of Diving Instructors In and Out of the Water

	Out of water		In the water	
	Initial	After one year of duty at the Escape Training Tank	Initial	After one year of duty at the Escape Training Tank
	cc (BTPS)	cc (BTPS)	cc (BTPS)	cc (BTPS)
TIDAL VOLUME				
Mean	1146	1390	1353	1370
S.D.	292	510	444	228
Number	8	8	8	8
P		>.1		>.1
INSPIRATORY RESERVE				
Mean	2892	2930	3326	3557
S.D.	219	382	560	715
Number	8	8	8	8
P		>.1		>.1
EXPIRATORY RESERVE				
Mean	1424	1701	736	816
S.D.	450	554	329	509
Number	8	8	8	8
P		>.1		>.1
VITAL CAPACITY				
Mean	5454	6021*	5408	5691
S.D.	580	848	637	724
Number	8	8	8	8
P		<.05		>.1
RESIDUAL VOLUME				
Mean	1918	1621	2022	1962
S.D.	570	287	616	606
Number	8	8	8	8
P		>.1		>.1
FUNCTIONAL RESIDUAL CAPACITY				
Mean	3342	3322	2646	2780
S.D.	854	522	641	944
Number	8	8	8	8
P		>.1		>.1
TOTAL LUNG CAPACITY				
Mean	7373	7643	7429	7652
S.D.	961	888	1105	1168
Number	8	8	8	8
P		>.1		>.1

* Difference statistically significant at the 5% level.

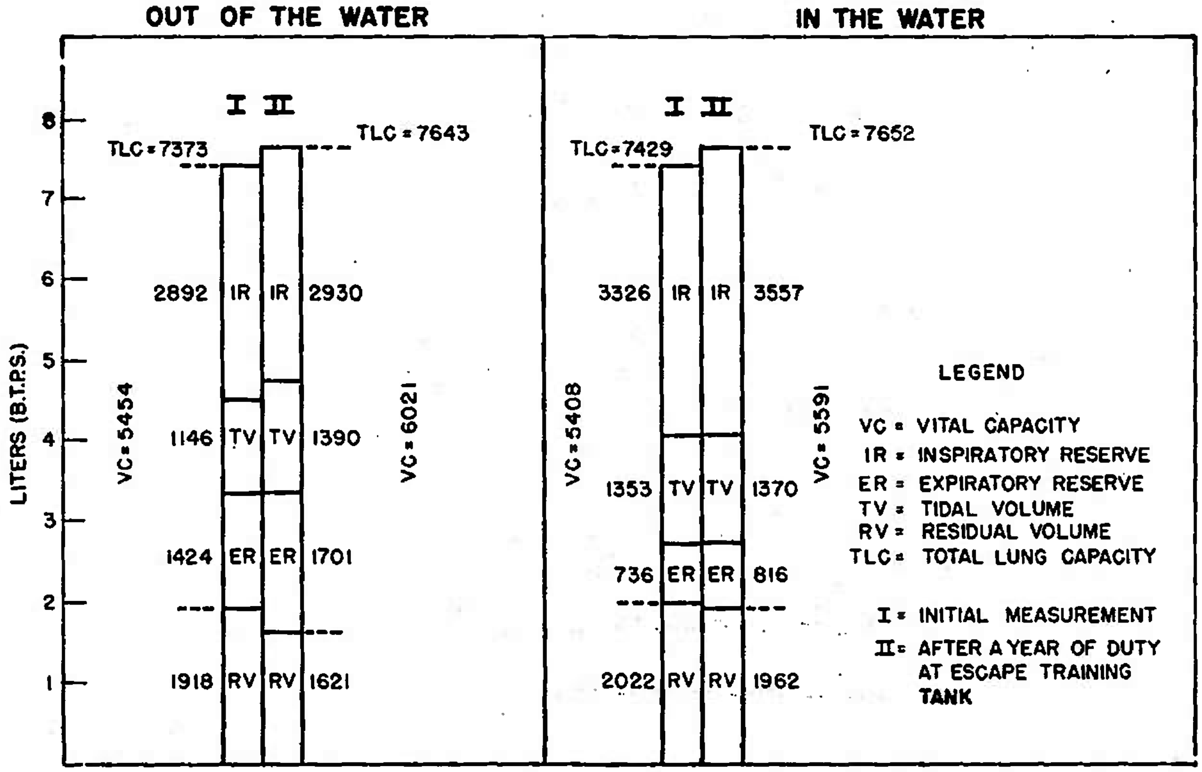

Figure 3.— Pulmonary Capacity Of 8 Tank Instructors Measured In And Out Of The Water

DISCUSSION

The larger lung volume of the Tank instructors as compared with those of a group of laboratory personnel representing average individuals could be produced by (a) natural selection, and (b) adaptation. Findings showing the measured vital capacity of Tank instructors 14.5 per cent higher than the vital capacity predicted on the basis of body surface area pointed in the direction of an adaptation. The longitudinal study definitely demonstrated that an adaptation takes place and that the Tank instructors increase their lung volumes (total capacity, inspiratory reserve, tidal volume, vital capacity) during their tour of duty.

This does not exclude a certain kind of natural selection in the case of very efficient skin divers among the group of Tank instructors. They have large lung capacities to start with. But the important finding is that all the Tank instructors increase their lung capacity during their tour of duty. The increase in inspiratory reserve and tidal volume is not achieved by a corresponding decrease in other pulmonary volume. Expiratory reserve remains approximately the same. Although residual volume decreases somewhat, the total lung capacity increases significantly

As to the cause of these adaptive changes in lung volumes, we might examine the working conditions of the Tank instructors a little more closely. Prior to diving, they take a deep breath in a position in which they are submerged up to the neck in the water. Under these conditions, the hydrostatic pressure on the chest was measured to be equivalent to a negative intrapulmonary pressure of -20 mm Hg. This finding is in agreement with data given by Rahn (7) and Fenn (8). Rahn (7) demonstrated that at -20 mm Hg. the inspiratory reserve and the tidal volume are markedly increased, while the expiratory reserve is decreased. Therefore the influence of the position in the water helps greatly to overcome the "stress" of skin diving, which involves maximal inspiration in an effort to hold the breath as long as possible.

The changes in lung volumes produced by the position in the water are similar to those observed during adaptation of the instructor, the difference being that the latter are actual and permanent changes resulting in an increased total lung capacity, while the former are only compensatory changes within the unaltered total lung capacity. Increases in inspiratory reserve, tidal volume, vital capacity, and total capacity facilitate maximal inspiration and increase the breathholding time. The "stress" in skin diving definitely is on the inspiratory side of the respiratory cycle, and the adaptation shows a response to this stress.

The observed changes in lung volumes allow the skin diver to reach a lower depth. Whether a skin diver can reach 100 feet or 120 feet without a squeeze depends on the relation of his total lung capacity to his residual air. If, for example, the lung volume of a diver at the surface is 6000 cc. and his residual air 1500 cc., he should be able to reach 100 feet (equivalent to four atmospheres), because his lung volume would be compressed to one fourth, or 1500 cc. At 132 feet (five atmospheres) the lung volume would be compressed to 1250 cc., which is less than his residual air, and lung tissues would be inverted into the larger passages and blood would be squeezed into the bronchi. It is evident that by increasing the total lung capacity or decreasing the residual air the diver can increase the depth to which he is able to go. This is exactly the adaptation which takes place in the instructors. An increase in total lung capacity has been demonstrated; a slight decrease in the residual air is suggested by the measurements. The adaptive changes found in lung volumes of Tank instructors bear a relationship to their respiratory pattern and tolerance to increased carbon dioxide tensions, which has been discussed by Schaefer (9).

CONCLUSIONS

1. Vital capacity, measured with the Vitalometer in a group of laboratory personnel and a group of Tank instructors, was found significantly larger in the Tank instructors.
2. When the measured vital capacity for each of the two groups was compared with vital capacity values predicted on the basis of body surface area (West formula), it was found that the measured values of the Tank instructors were 14.6 per cent higher than predicted while those of the laboratory personnel were 0.56 per cent lower than predicted.
3. Measurements of the subdivisions of the lung volumes showed that the Tank instructors had significantly larger total capacity, vital capacity, inspiratory reserve.
4. A longitudinal study of the lung volumes of instructors carried out for a period of one year following their assignment to the Escape Training Tank exhibited a significant increase in total lung capacity, vital capacity, inspiratory reserve, and tidal volume.
5. Additional measurements of lung volumes made in a group of Tank instructors standing on a ladder up to the neck in water reflected changes in the same direction as observed in determinations made out of the water.

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3. Adaptation to stress of "skin" diving

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Rpt. No. 1 on Bureau of Medicine and Surgery, Navy Dept., Project NM 002 015.12, Nov 54, 12 pp plus iii, 3 figs., 4 tables, 9 refs.

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Based on a common experience of instructors at the Escape Training Tank, namely, that during their tour of duty, they learn to hold their breath longer and breathe differently, a study of their pulmonary capacities was undertaken. Vital capacity, inspiratory reserve, and total lung capacity of the Tank instructors were found significantly larger than those of laboratory personnel representing average individuals. When measured vital capacities of the two groups were compared with vital capacities predicted on the basis of body surface area, the measured values of the Tank instructors were 14.6% higher than predicted, while those of the laboratory personnel were 0.56% lower. A longitudinal study of the lung volumes of instructors performed over a period of one year following their assignment to the Escape Training Tank demonstrated a significant increase in inspiratory reserve, tidal volume, vital capacity, and total lung capacity, while expiratory reserve and residual volume did not change significantely. These findings indicate an adaptation of the lung volume to the stress of skin diving.

UNCLASSIFIED

1. Lung volumes in divers
2. Submarine escape training, effect on instructors
3. Adaptation to stress of "skin" diving

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